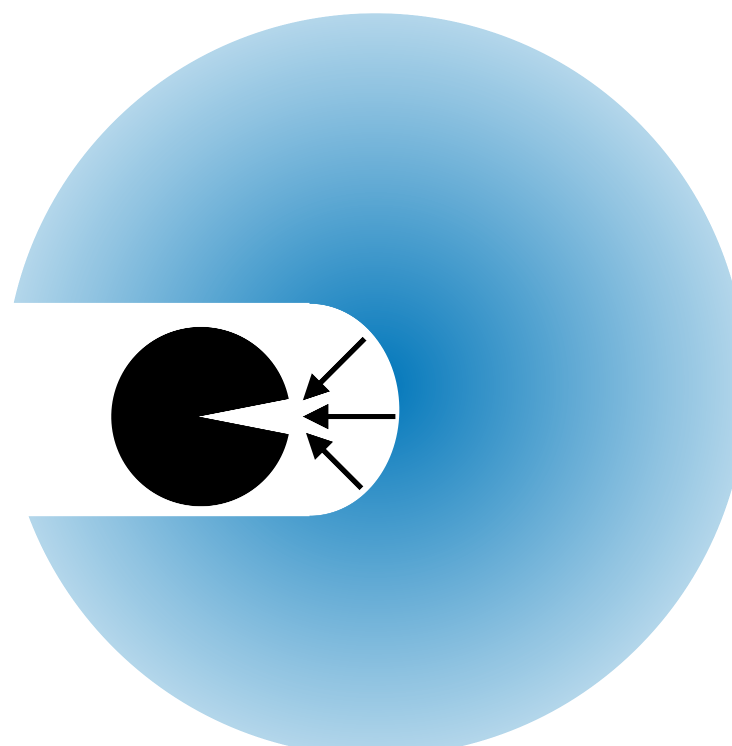
Black hole eating boson star



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My collaborators

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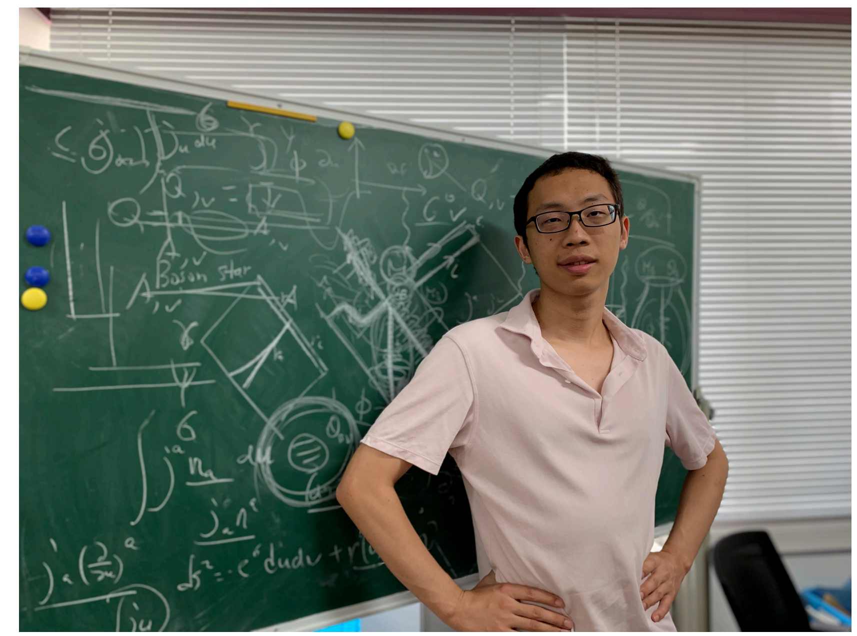
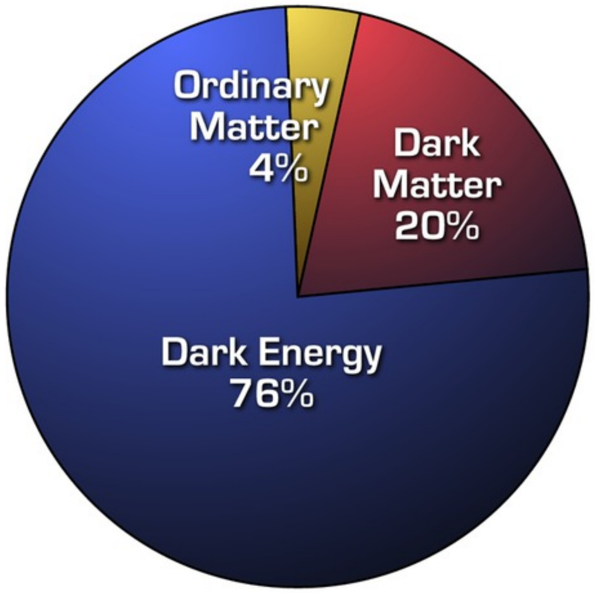


Zhen Zhong

Beyond GR and SM



- Mystery in our Universe
  - Dark matter ??
  - Dark energy ??
  - Quantum theory of gravity ??
- They may be hints of new physics.
  - New particle ??
  - Modified gravity ?? ➡ They predict light fields.
  - String theory ?? et al.
- Light complex scalar fields are one of the candidate.

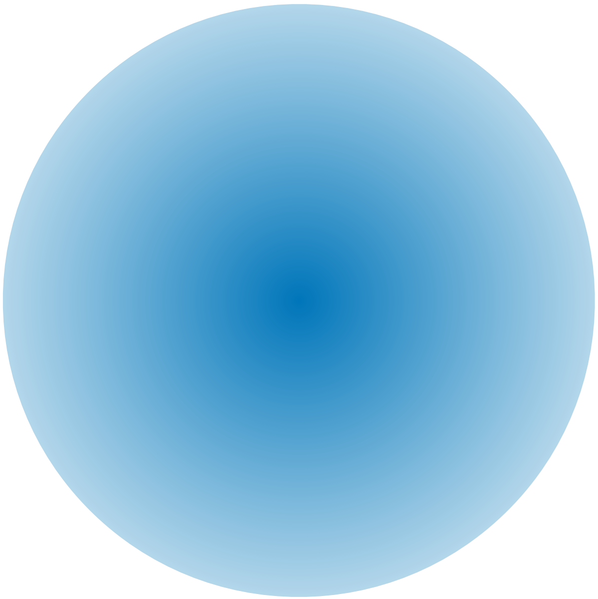
$$S = \int d^4x\sqrt{-g}\left(\frac{R}{16\pi} - g^{\mu\nu}\nabla_\mu\psi\nabla_\nu\psi^* - \mu^2|\psi|^2\right)$$

ψ : complex scalar field

Light scalar field in our Universe

- Typical configuration of the light field.

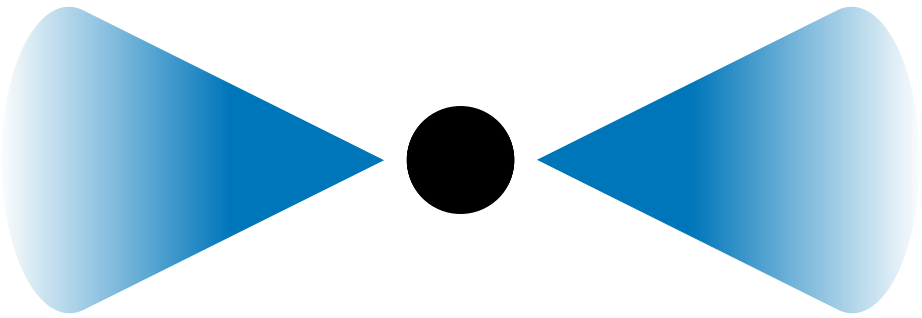
Boson star
= self-gravitating object



- compact object
- dark matter halo

$$\frac{M_{\mathrm{BS}}}{M_{\odot}} = 9 \times 10^{9} \frac{100\mathrm{pc}}{R_{\mathrm{BS}}} \left(\frac{10^{-22}\ \mathrm{eV}}{\mu} \right)^{2}$$

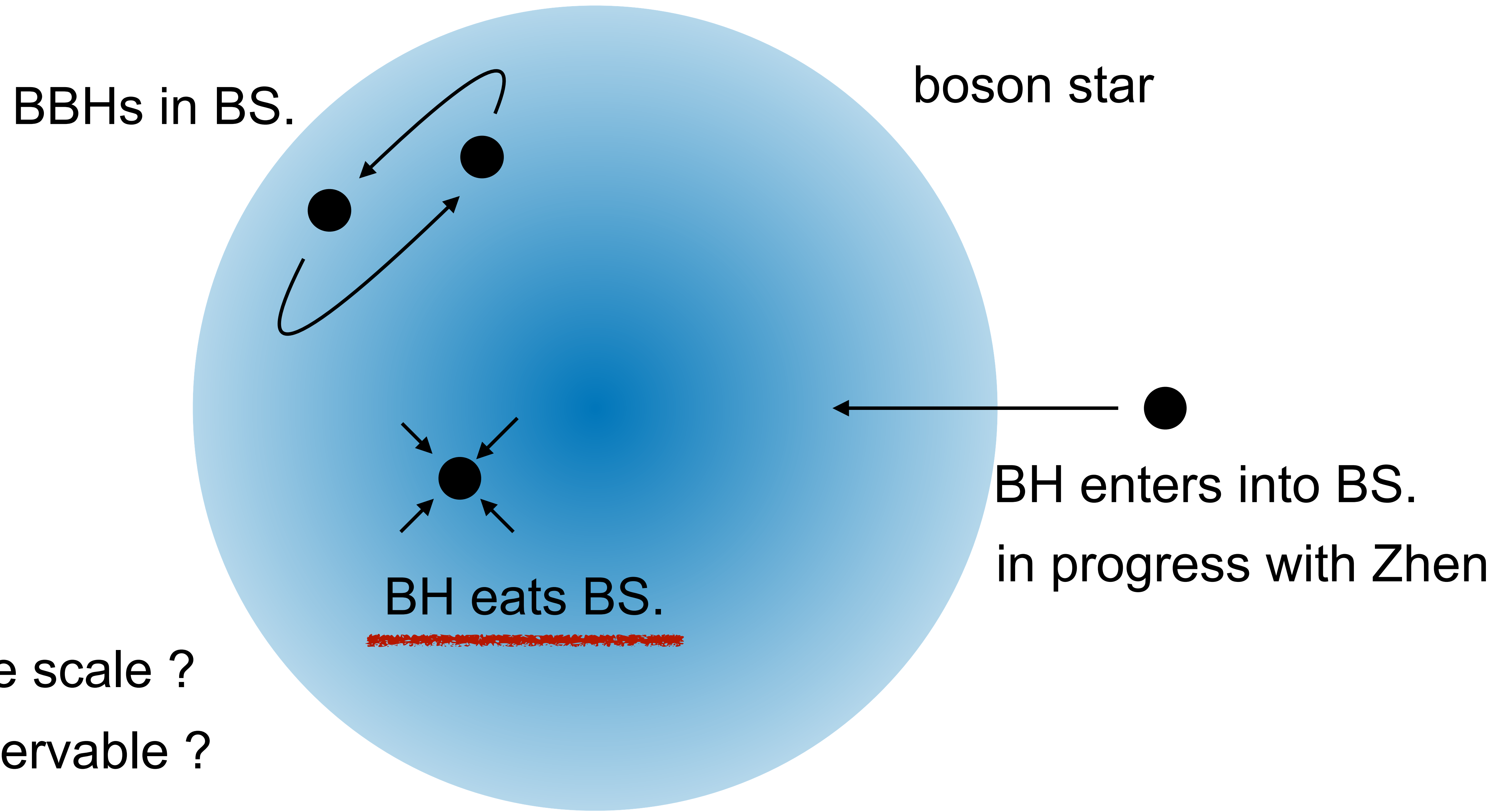
Gravitatioanl atom
= test field configuration
around BH



- source of GW
- superradiant instability

Possible interactions with BHs

- Dark matter halo interact with BHs

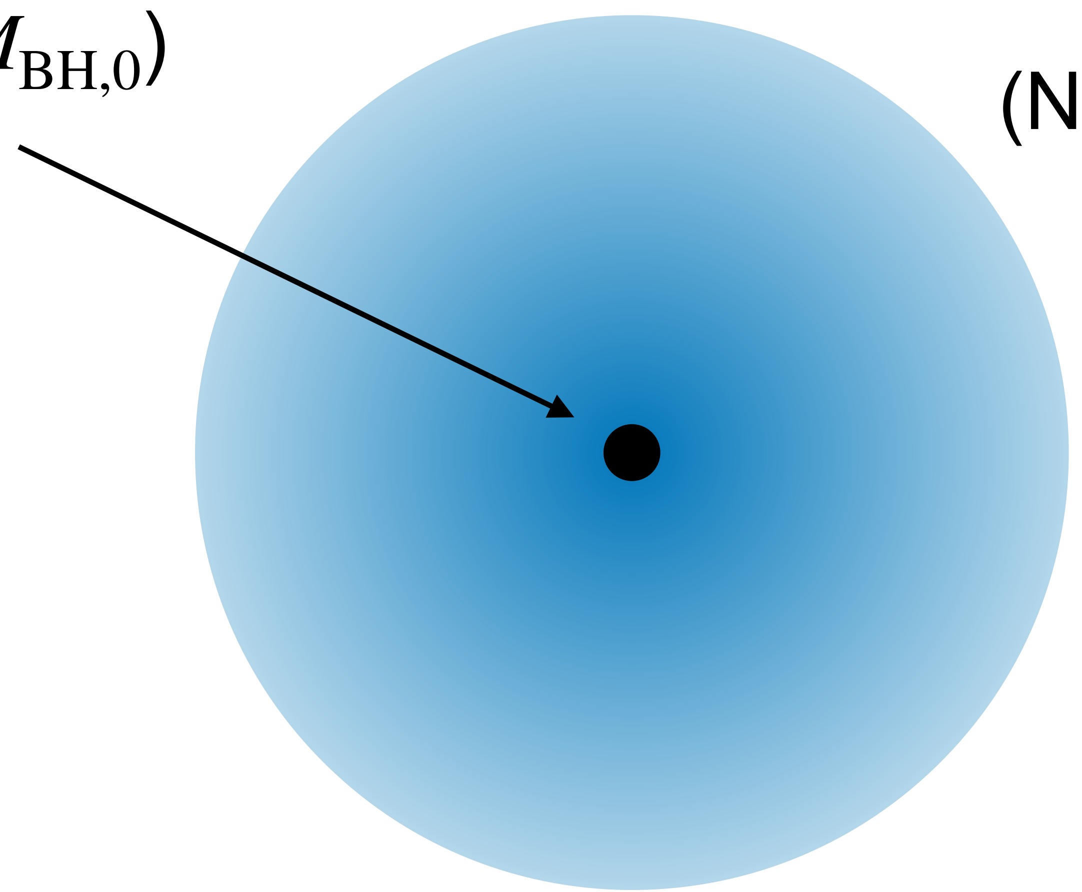


- Time scale ?
- Observable ?
- Typical dynamics ?

Set up

- Set up : BS-BH system
  - Spherical symmetry (for simplicity) : non-spinning BH, BS
  - Initial profile is boson star profile with BH
  - We consider the evolution of metric and the complex scalar field.

Black hole ($M_{\mathrm{BH},0}$)



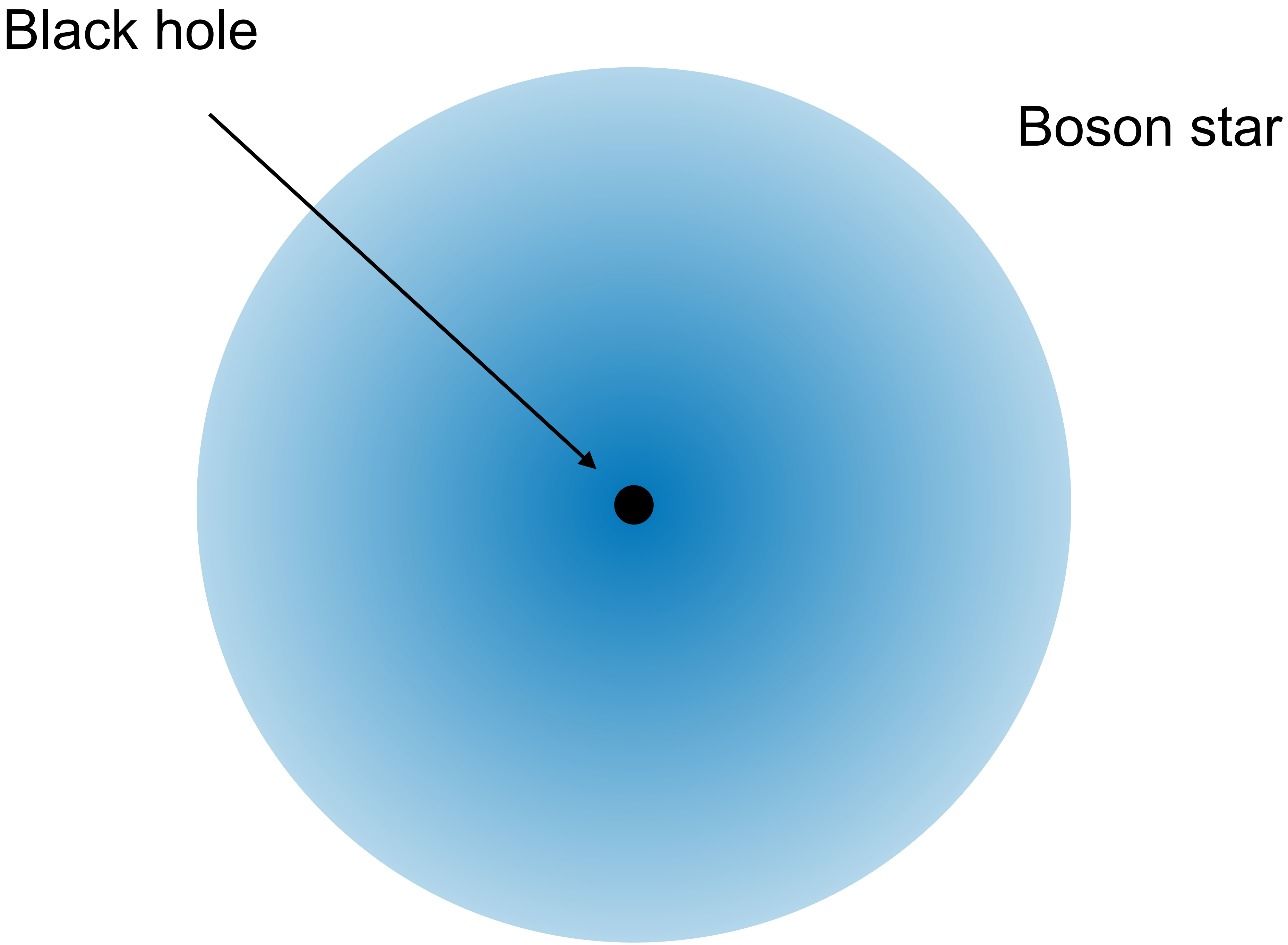
(Nodeless) boson star

Parameters

$\mu M_{\mathrm{BH},0}, \Psi_c$

Initial Data

Possible Scenario



Initial Data

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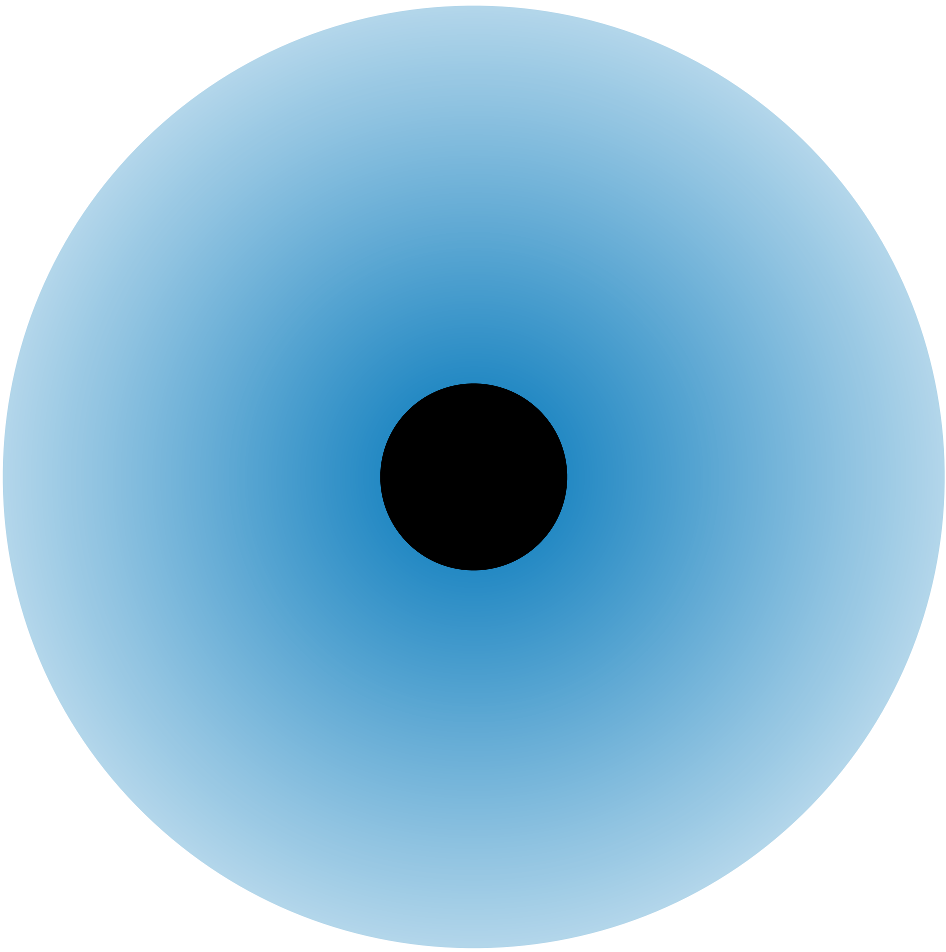
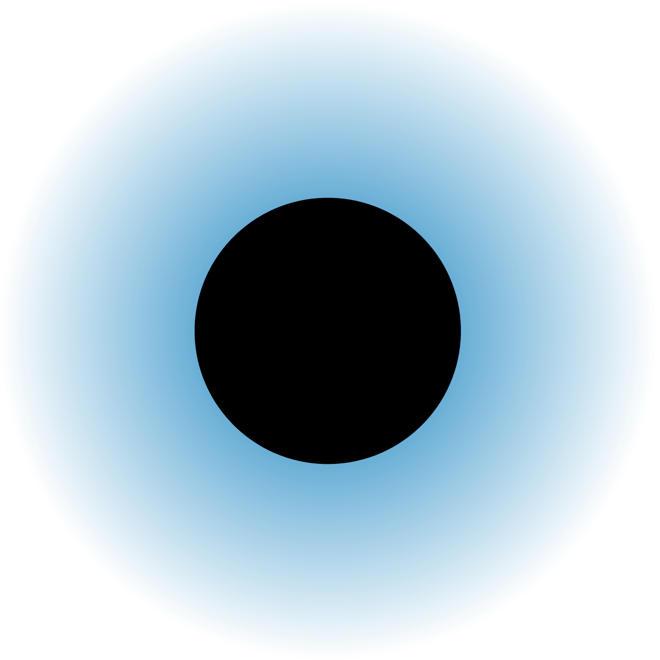


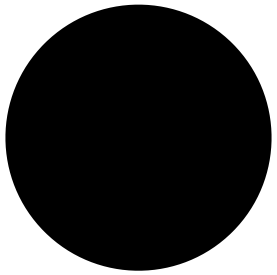
BH eats boson star.

Possible Scenario



Formation of gravitational atom ?

Possible Scenario



Final state

Our strategy

- Gravitational atom in late time
  - Test field configuration ($E_\Psi \ll M_{\rm BH}$)

$$\Box_{\rm BH}\Psi - \mu^2\Psi = 0 \quad \Longrightarrow \quad \omega = \omega_{\rm Re} + i\omega_{\rm Im}$$

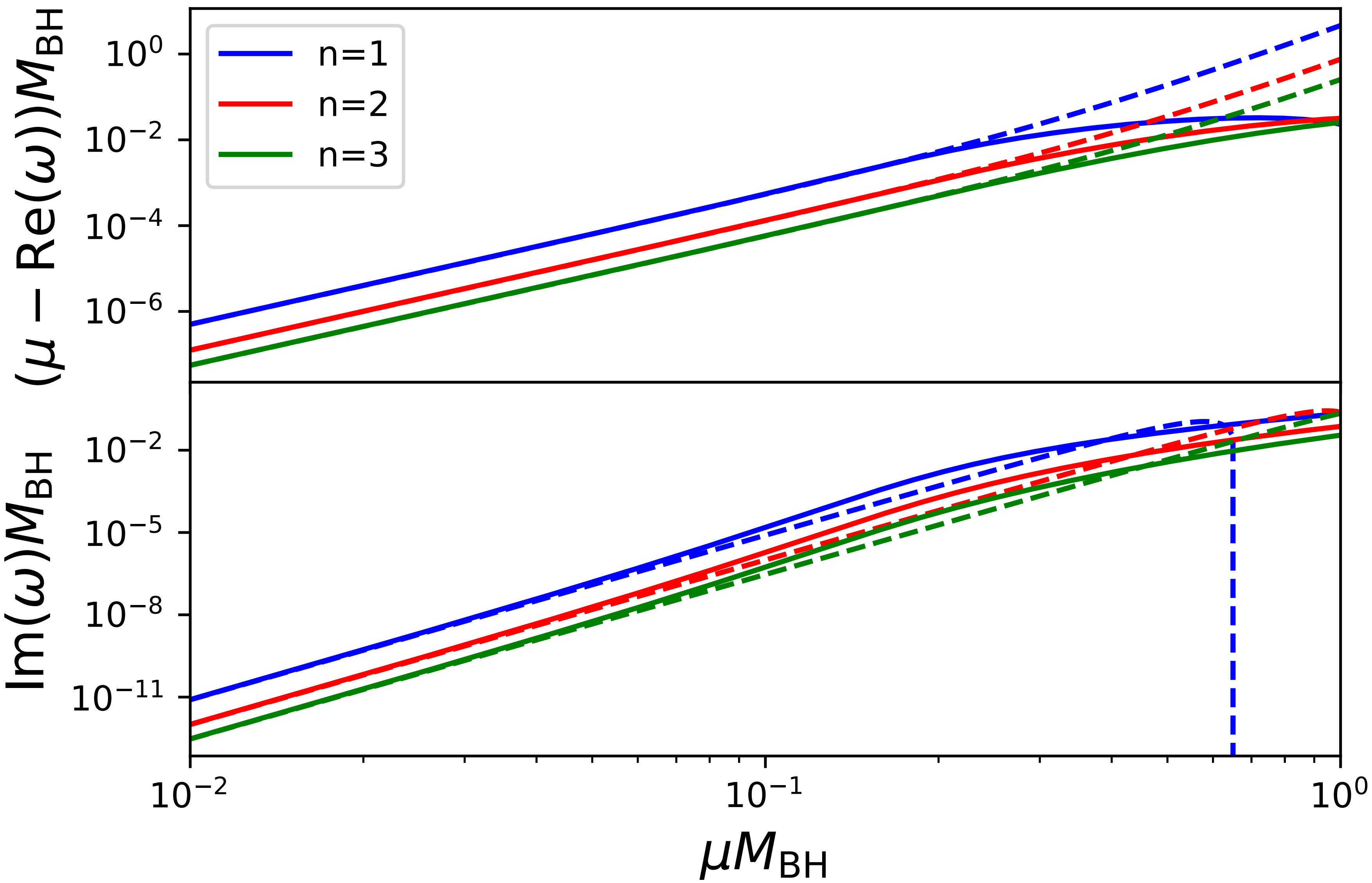
- Schroedinger-Poisson system
  - Newtonian approximation

$$\begin{cases} ds^2 = (1+2\Phi_N)dt^2 + \delta_{ij}dx^i dx^j \\ \Psi = \mu^{-1/2}\bar{\Psi}e^{-i\mu t} \end{cases} \quad \Longrightarrow \quad \begin{cases} i\dfrac{\partial\bar{\psi}}{\partial t} = -\dfrac{1}{2\mu}\Delta\bar{\psi} + \mu\left(-\dfrac{M_{\rm BH}}{r} + \delta\Phi_N\right)\bar{\psi} \\ \Delta\delta\Phi_N = 8\pi\mu\bar{\psi}_0^2 \end{cases}$$

  - BH horizon effect is not included.
- Numerical relativity
  - All effects are included.
  - Simulations with $\mu M_{\rm BH} \ll 1$ or $\Psi_c \ll 0.01$ are difficult.

Gravitational atom

- Spectrum of gravitational atom
  - Leaver method



Schroedinger-Poisson system

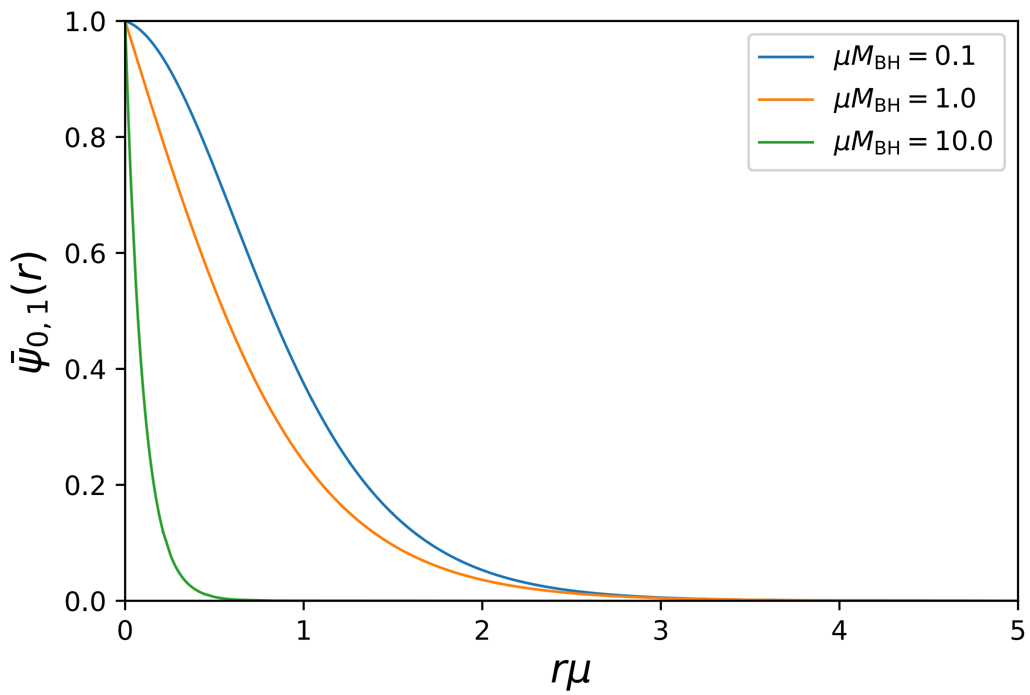
- Configuration of SP system

$$\begin{cases} -\gamma\bar{\psi} = -\dfrac{1}{2\mu}\Delta\bar{\psi} + \mu\left(-\dfrac{M_{\mathrm{BH}}}{r} + \delta\Phi_N\right)\bar{\psi} \\ \Delta\delta\Phi_N = 8\pi\mu\bar{\psi}_0^2 \end{cases}$$

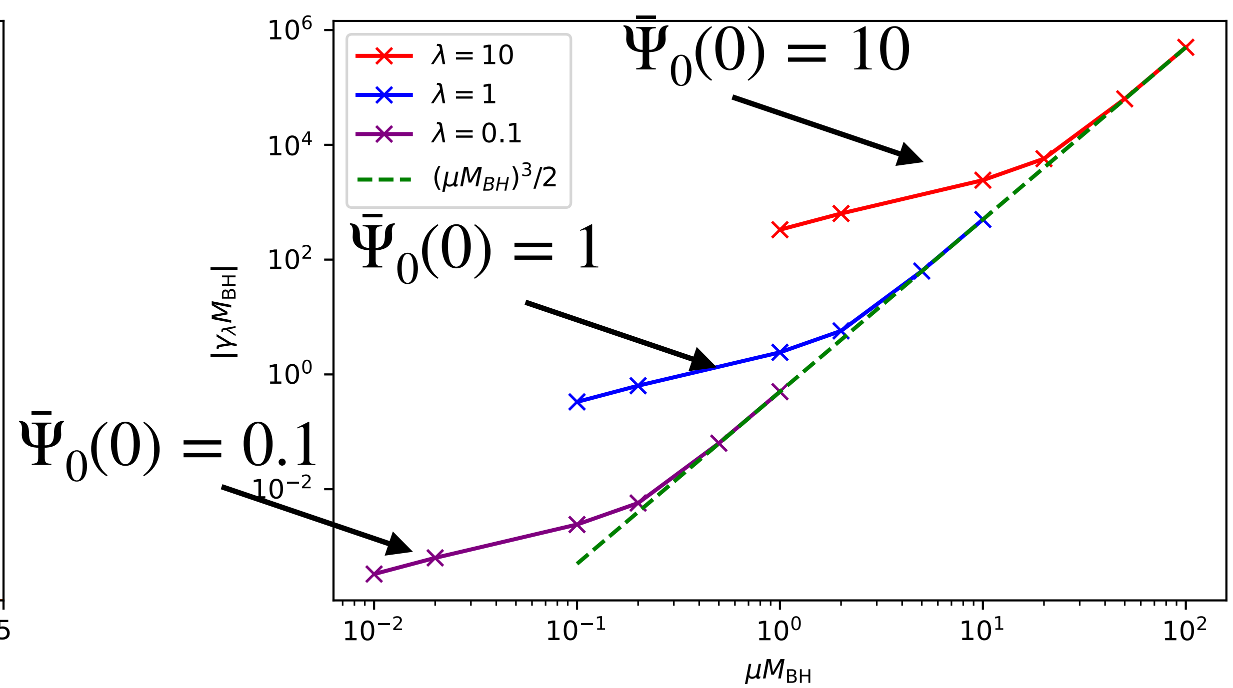
Boundary condition

$$\begin{cases} \bar{\psi}_0 \sim e^{-\sqrt{2\mu|\gamma|}\,r} \\ \delta\Phi \sim -\dfrac{M_{\mathrm{BS}}}{r} \end{cases}$$

Radial profile



Spectrum



Schroedinger-Poisson system

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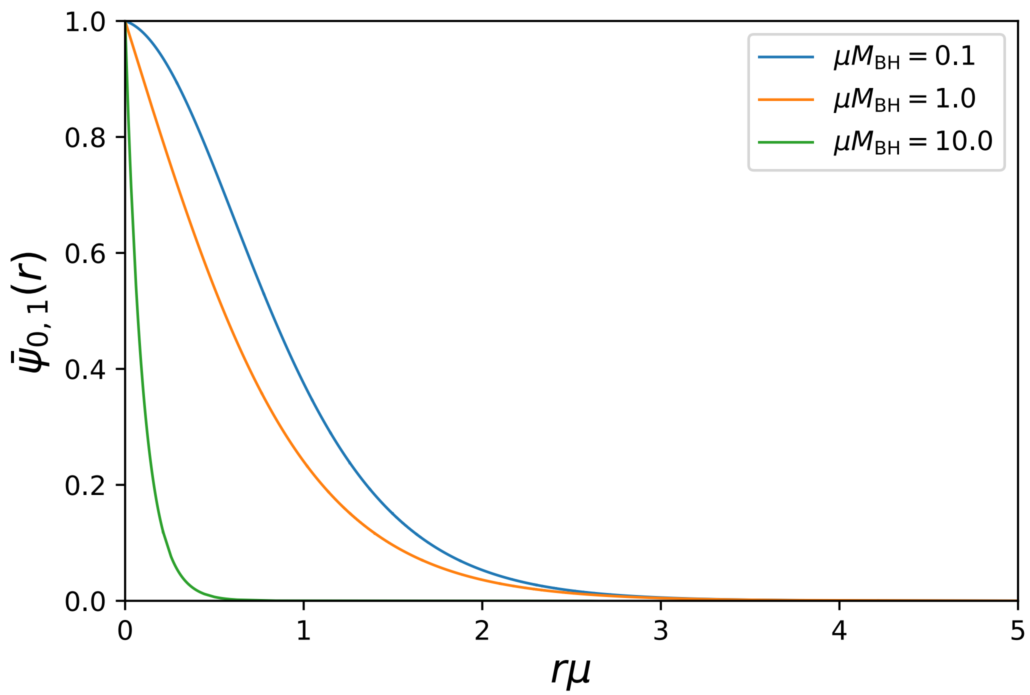
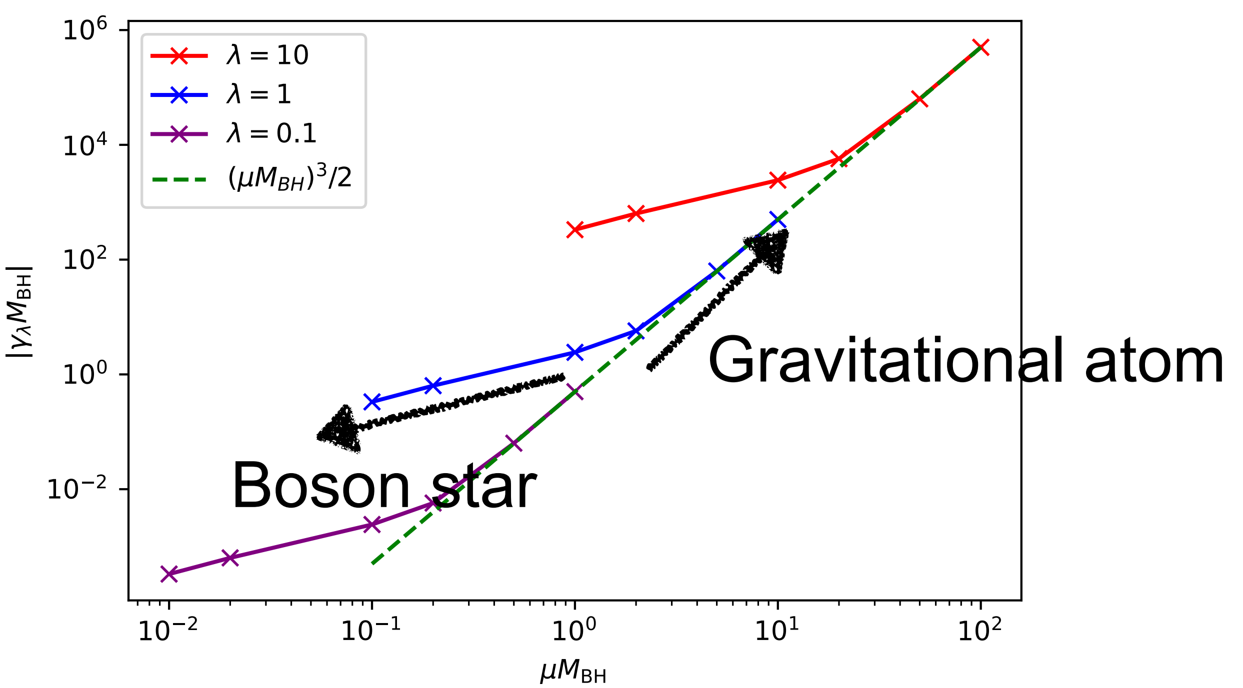


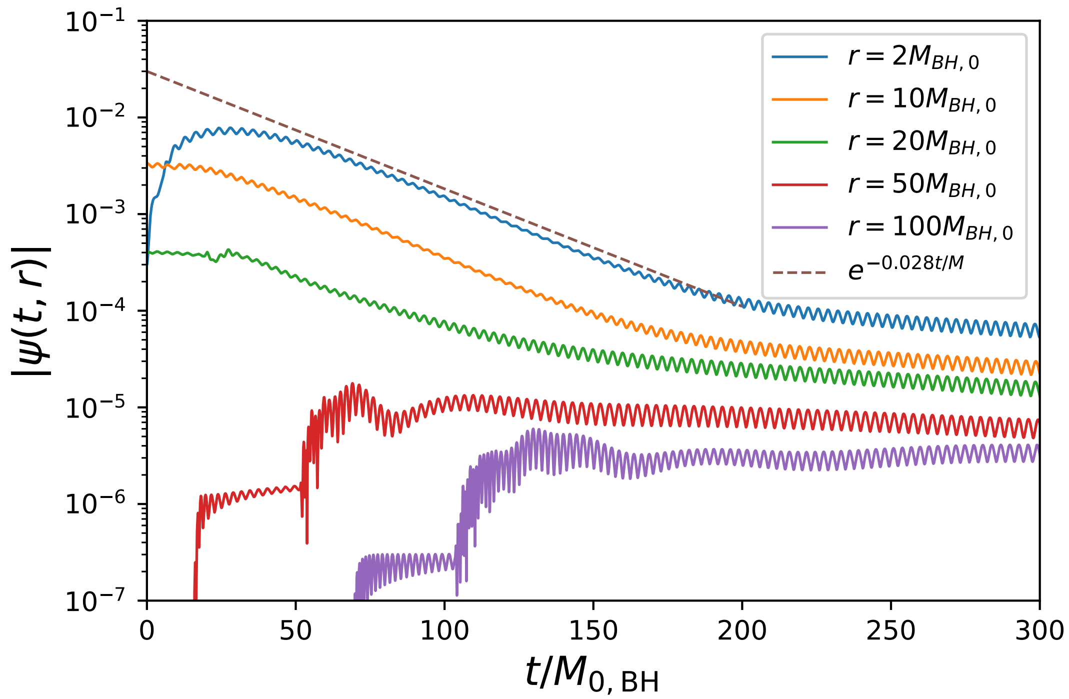
Spectrum



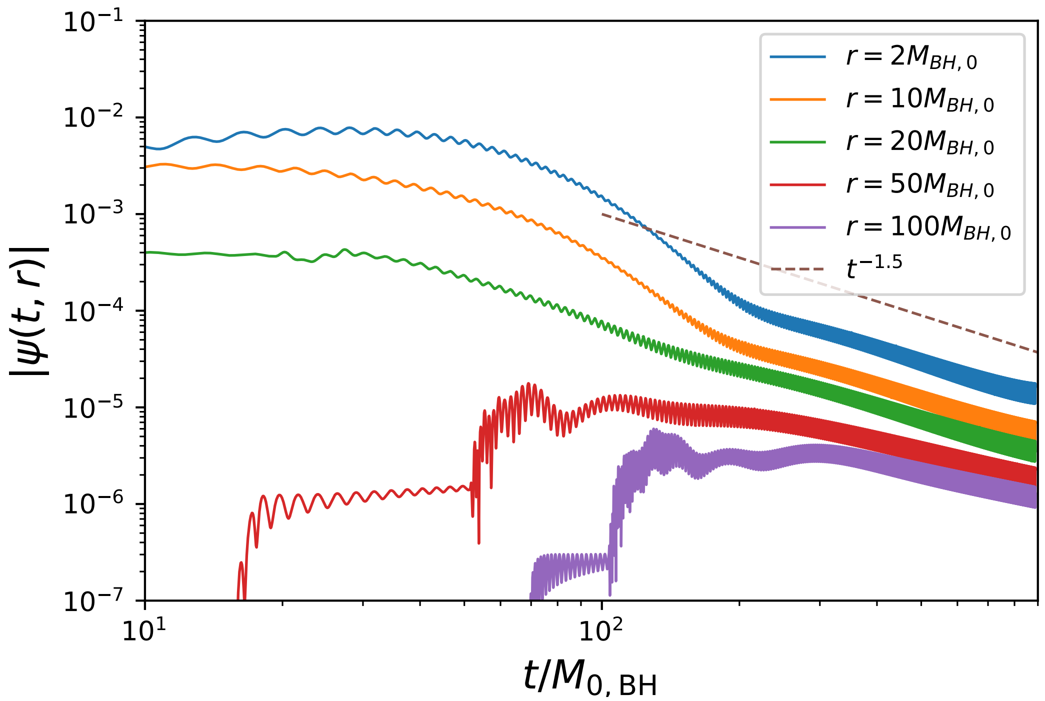
Numerical relativity

- Here, we show "preliminary" results. $\mu M_{0,\mathrm{BH}} = 1, \psi_c = 0.01$

The scalar field decays exponentially around BH in early phase.



In late time, we observe power-law tail.



In general, we can expect power low tail

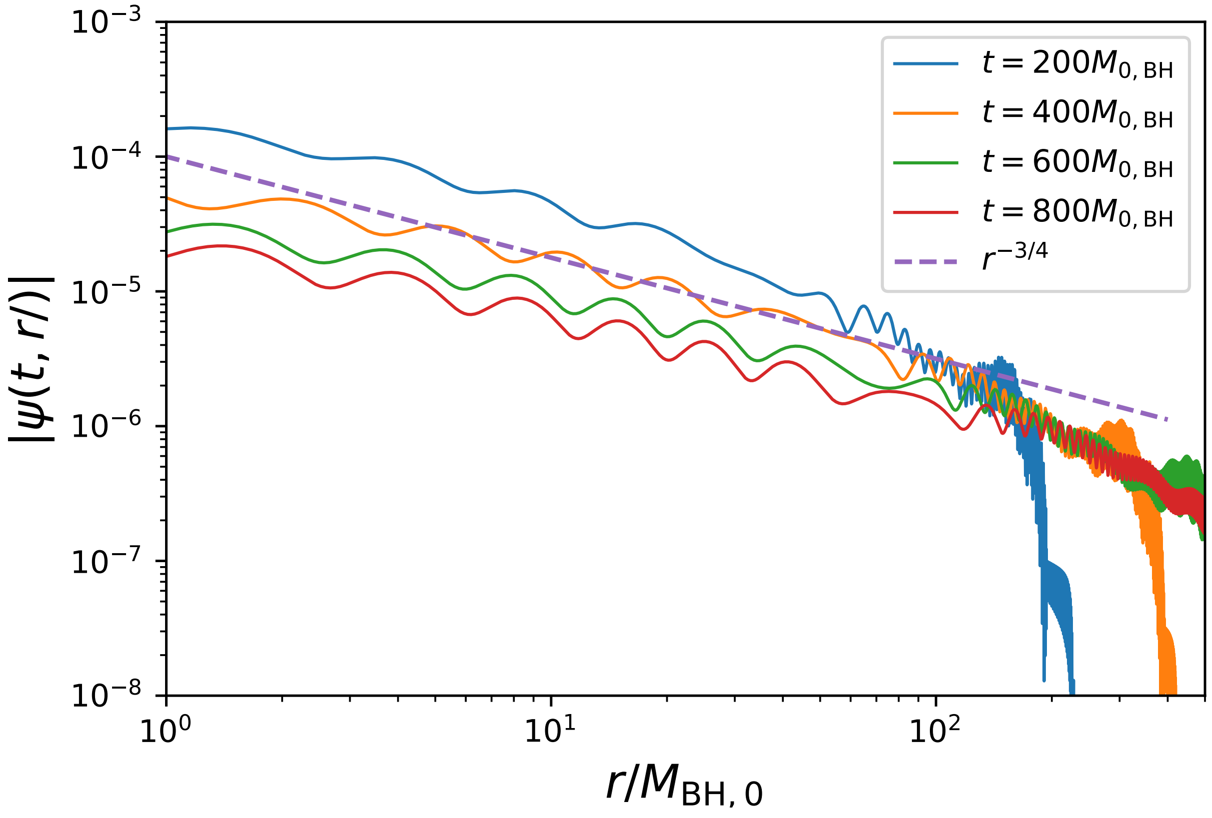
$$\psi \sim t^p \sin(\mu t)$$

$$\begin{cases} p = -(l + 3/2) & \text{at late time} \\ p = -5/6 & \text{at very late time} \end{cases}$$

Preliminary results

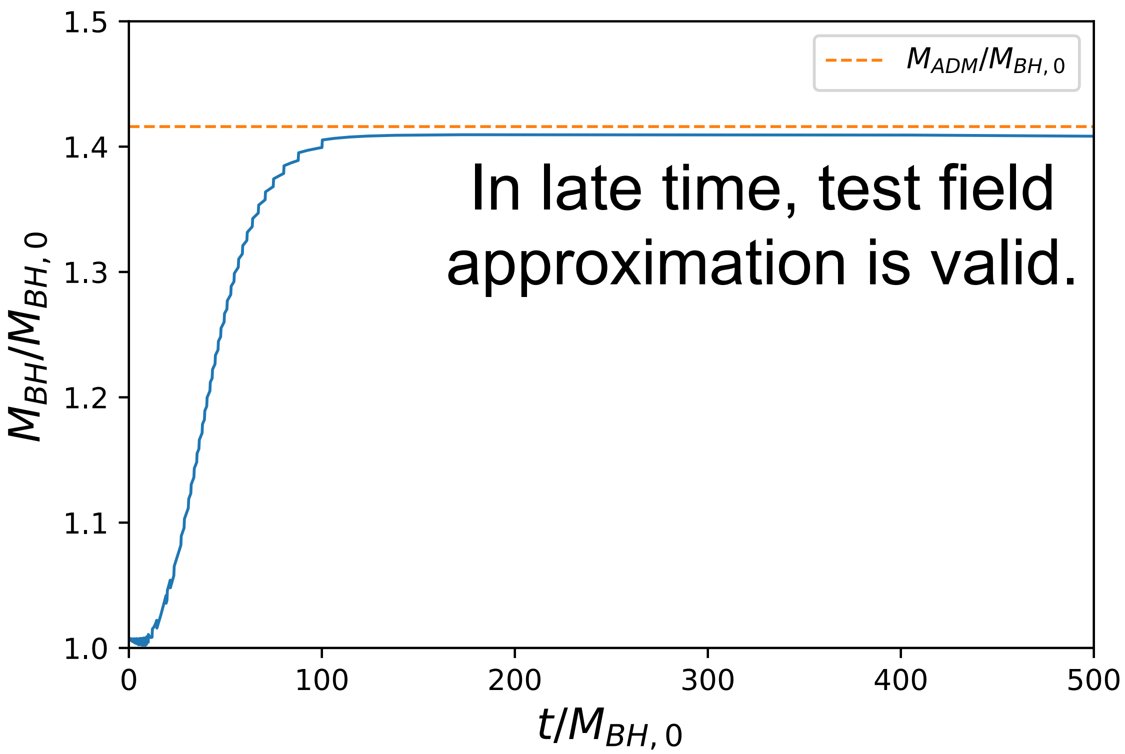
$$\mu M_{0,\mathrm{BH}} = 1, \psi_c = 0.01$$

Late time radial profile of scalar field is $\sim r^{-3/4}$



cf: Lam (2019)

BH eat almost boson star energy in early phase.



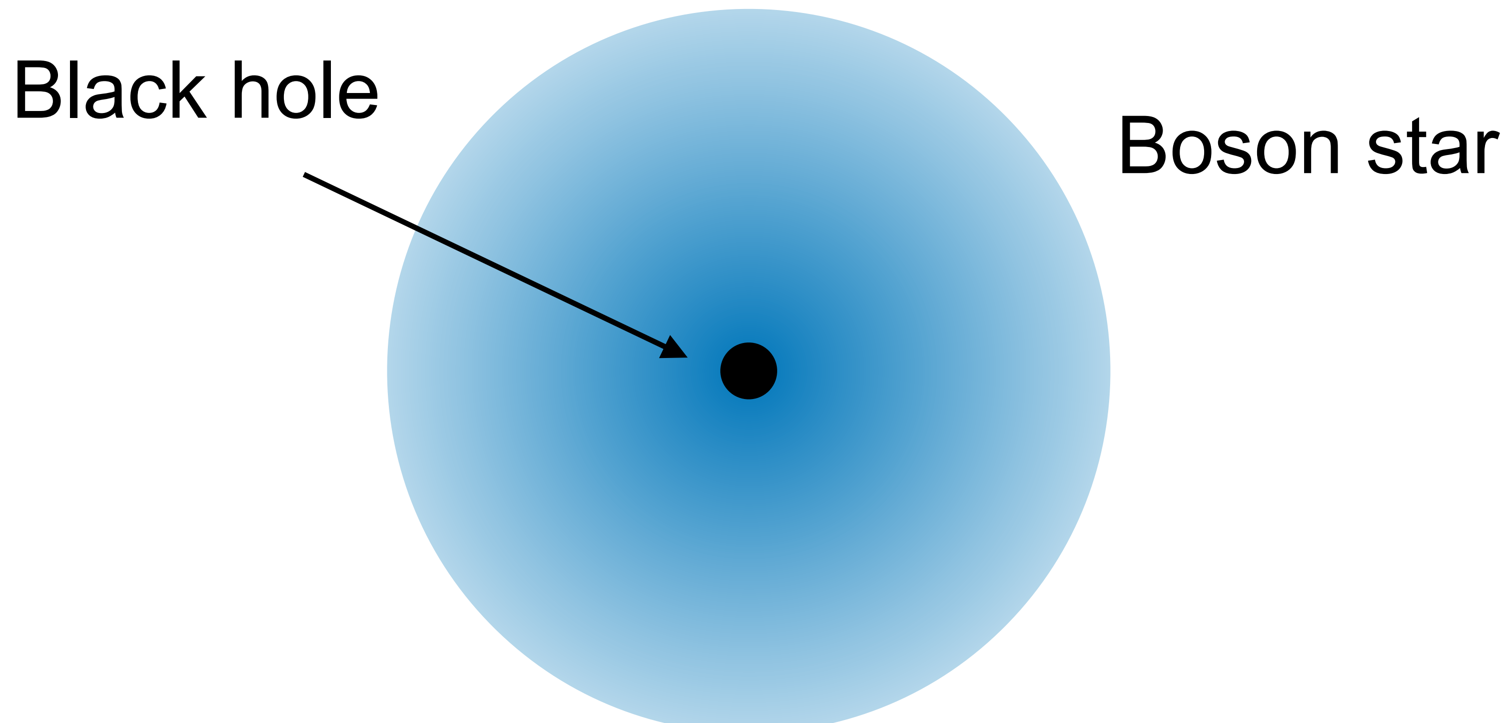
In late time, $\mu M_{BH} \simeq 1.4$

The life time of the corresponding gravitational atom is very short.

power low behavior dominates.

Summary

- We discussed the accretion process of boson star into black hole.



- Gravitatioanl atom : spectrum
- Schrodeinger-Poisson system : configuration in Newtonian limit
- Numerical relativity
  - For $\mu M_{0,\mathrm{BH}} = 1, \psi_c = 0.01$

    late time power low decay, and power low profile.
- We need further simulations….

Finish